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For: ELECTRON-EMITTING DEVICE, ELECTRON-EMITTING APPARATUS, IMAGE DISPLAY APPARATUS, AND LIGHT-EMITTING APPARATUS	:) :) :	March 12, 2004

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Commissioner for Patents
P.O. Box 1450
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SUBMISSION OF SWORN TRANSLATIONS OF PRIORITY APPLICATIONS

Sir:

Applicant submits herewith sworn English translations of Japanese Application Nos. 2000-265819, filed September 1, 2000, and 2001-255145, filed August 24, 2001, from which this application claims priority.[1]

1/ Declarations stating that the English translations of Japanese Application Nos. JP 2000-256819 and JP 2001-255145 are accurate are submitted herewith.

Applicant's undersigned attorney may be reached in our New York office by telephone at (212) 218-2100. All correspondence should continue to be directed to our below listed address.

Respectfully submitted,

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DECLARATION

I, NOBUAKI KATO, a Japanese Patent Attorney registered No.08517, of Okabe International Patent Office at No. 602, Fuji Bldg., 2-3, Marunouchi 3-chome, Chiyoda-ku, Tokyo, Japan, hereby declare that I have a thorough knowledge of Japanese and English languages, and that the attached pages contain a correct translation into English of the priority documents of Japanese Patent Application No. 2000-265819 filed on September 1, 2000 in the name of CANON KABUSHIKI KAISHA.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that wilful false statements and the like so made, are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such wilful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 19th day of August, 2003

NOBUAKI KATO

PATENT OFFICE
JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application: September 1, 2000

Application Number: Japanese Patent Application No. 2000-265819

Applicant(s): CANON KABUSHIKI KAISHA

September 11, 2001

Commissioner, Patent Office KOZO OIKAWA

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[Title of the Invention]	ELECTRON-EMITTING DEVICE, ELECTRON-EMITTING APPARATUS, ELECTRON SOURCE, IMAGE-FORMING APPARATUS, AND MANUFACTURING METHOD OF ELECTRON-EMITTING DEVICE
[Number of Claims]	31
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[Title of the Invention] Electron-Emitting Device, Electron-Emitting Apparatus, Electron Source, Image-Forming Apparatus, And Manufacturing Method Of Electron-Emitting Device

[What is claimed is]

[Claim 1]

An electron-emitting device forming

a pair of electrodes;

first voltage application means for applying a voltage between said pair of electrodes;

a cathode connected to an electrode on a lower electric potential side of said pair of electrodes electrically, said cathode having an electron-emitting member;

an extraction electrode connected to an electrode on a higher electric potential side of said pair of electrodes electrically;

an insulating substrate supporting said cathode and said extraction electrode so as to be opposed to each other with a gap between them;

an anode arranged so as to be opposed to said substrate in parallel with said substrate, said anode receiving reached electrons emitted from said cathode;

second voltage application means for applying a

voltage between said anode and said cathode; and

an electron-emitting portion in said electron-emitting member at a height between a plane including said extraction electrode and a plane including said anode, said device is characterized in that

when the distance of said gap is d; an electric potential difference at a time when said first voltage application means drives said electron-emitting device is V1; a distance between said anode and said substrate is H; and a potential difference between said anode and said cathode is V2, said potential difference generated by said second voltage application means, then an electric field at driving E1 = V1/d is within a range from 1 to 50 times as large as an electric field E2 = V2/H.

[Claim 2]

An electron-emitting device according to claim 1, wherein said electron-emitting member is formed on said cathode on said anode side, and a thickness of said cathode is thicker than a thickness of said extraction electrode.

[Claim 3]

An electron-emitting device according to claim 1, wherein an end of said electron-emitting member on said extraction electrode is formed to be located in said

gap.

[Claim 4]

An electron-emitting device according to claim 1, wherein said electron-emitting member is formed on said cathode on said anode side, and said substrate has a difference in level between said extraction electrode and said cathode, and further said cathode is positioned to be closer to said anode than to said extraction electrode with the difference in level located between them.

[Claim 5]

An electron-emitting device according to any one of claims 1-4, wherein said electron-emitting member is made of a material containing carbon as a main ingredient.

[Claim 6]

An electron-emitting device according to claim 5, wherein said material containing carbon as a main ingredient is an aggregate of fibrous carbon.

[Claim 7]

An electron-emitting device according to claim 6, wherein said aggregate of fibrous carbon comprises a graphite nanofiber, a carbon nanotube, amorphous carbon, all grown up through catalyst particles, or a mixture of these materials.

[Claim 8]

An electron-emitting device according to claim 7, wherein said catalyst particles are made of Pd, Ni, Fe, Co or an alloy of these substances.

[Claim 9]

An electron source characterized by at least a device row made by arranging a plurality of said electron-emitting devices according to any one of claims 1-8 in parallel to connect said arranged electron-emitting device.

[Claim 10]

An electron source characterized by at least a device row made by arranging a plurality of said electron-emitting devices according to any one of claims 1-8, and wiring to drive said devices is arranged in a matrix.

[Claim 11]

An image-forming apparatus characterized by said electron source according to claim 10, a fluorescent substance as said anode, and a mechanism for controlling an electron quantity of each electron-emitting device by means of an information signal.

[Claim 12]

A manufacturing method of an electron-emitting device, said method characterized by the steps of:

forming a pair of electrodes formed on an insulating substrate with a gap between them;

forming metal oxide particles connected to either of said pair of electrodes electrically;

performing reduction coagulation of said metal oxide particles to be metal particles; and

growing fibrous carbon on said metal particles.

[Claim 13]

An electron-emitting device including a first electrode and a second electrode disposed on a surface of a substrate with a gap formed between said first electrode and said second electrode; said device forming an electric field substantially parallel to said surface of said substrate by applying electric potential higher than that of said first electrode to said second electrode, said device emitting electrons, said device characterized in that a plurality of columnar substances containing carbon as a main ingredient is arranged on said first electrode.

[Claim 14]

An electron-emitting device according to claim 13, wherein a material more effective in accelerating deposition of the carbon than a material of said first electrode is provided between said columnar substances containing the carbon as the main ingredient and said

first electrode.

[Claim 15]

An electron-emitting device according to claim 14, wherein said material effective in accelerating the deposition of the carbon is one comprising Pd, Ni, Fe, Co or an alloy formed of said substances.

[Claim 16]

An electron-emitting device according to claim 14 or 15, wherein said material effective in accelerating the deposition of the carbon is provided in a form of a plurality of particles on said first electrode.

[Claim 17]

An electron-emitting device according to claim 16, wherein said plurality of particles are provided on said first electrode at a density of 10^{10} particles/cm^2 or higher.

[Claim 18]

An electron-emitting device according to any one of claims 13-17, wherein a thickness of said first electrode is thicker than the thickness of said second electrode.

[Claim 19]

An electron-emitting device according to any one of claims 13-18, wherein said columnar substances containing the carbon as the main ingredient are ones

selected in a group of carbon nanotube and a graphite nanofiber.

[Claim 20]

An electron-emitting apparatus including an electron-emitting device and a substantially plane-like anode electrode arranged to be opposed to said electron-emitting device, said apparatus characterized in that said electron-emitting device is one according to any one of claims 13-19.

[Claim 21]

An electron-emitting apparatus according to claim 20, wherein a distance between said anode electrode and a surface of said first electrode is shorter than a distance between said anode electrode and a surface of said second electrode.

[Claim 22]

An electron-emitting apparatus according to claim 20, wherein distances between said anode electrode and ends of said columnar substances containing the carbon as the main ingredient on a side at which said columnar substances are not connected to said first electrode are shorter than a distance between said anode electrode and the surface of said second electrode.

[Claim 23]

An electron-emitting apparatus comprising:

a first electrode including an electron-emitting member, and a second electrode for extracting electrons from said electron-emitting member;

first electric potential application means for applying to said second electrode electric potential higher than electric potential applied to said first electrode;

a substrate including said first and said second electrodes on a surface of said substrate so as to oppose said first and said second electrodes to each other with a gap;

an anode electrode including a surface parallel to the surface of said substrate substantially, said anode electrode disposed with a distance from said substrate; and

second electric potential application means for applying to said anode electric potential higher than electric potential applied to said second electrode, said apparatus characterized in that

a plane containing a part of a surface of said electron-emitting member, said plane substantially parallel to the surface of said substrate, is positioned at a position between a plane containing a part of a surface of said extraction electrode, said plane substantially parallel to the surface of said

substrate, and the surface of said anode electrode.

[Claim 24]

An electron-emitting apparatus according to claim 23, characterized in that when a distance between said first electrode and said second electrode is d; a difference between the electric potential applied to said first electrode and the electric potential applied to said second electrode, both potential applied by said first electric potential application means, is V1; the distance between the surface of said anode electrode and the surface of said substrate is H; and a difference between the electric potential applied to said anode by said second electric potential application means and the electric potential applied to said first electrode is V2, then an electric field E1 = V1/d is within the range from 1 to 50 times as large as an electric field E2 = V2/H.

[Claim 25]

An electron-emitting apparatus according to claim 23 or 24, characterized in that said electron-emitting member is made of a plurality of columnar substances containing carbon as a main ingredient.

[Claim 26]

An electron-emitting apparatus according to claim 25, characterized in that a material more effective in

accelerating deposition of the carbon than the material of said first electrode is provided between said columnar substances containing the carbon as the main ingredient and said first electrode.

[Claim 27]

An electron-emitting apparatus according to claim 25, characterized in that said material effective in accelerating deposition of the carbon is one comprising Pd, Ni, Fe, Co or an alloy formed of said materials.

[Claim 28]

An electron-emitting apparatus according to claim 26 or 27, characterized in that said material effective in accelerating deposition of the carbon is provided in the form of a plurality of particles on said first electrode.

[Claim 29]

An electron-emitting apparatus according to claim 28, characterized in that said plurality of particles is provided on said first electrode at a density of 10^{10} particles/cm^2 or higher.

[Claim 30]

An electron-emitting apparatus according to any one of claims 23-29, characterized in that the thickness of said first electrode is thicker than the thickness of said second electrode.

[Claim 31]

An electron-emitting apparatus according to any one of claims 23-30, characterized in that said columnar substances containing the carbon as the main ingredient are ones selected in a group of carbon nanotube and a graphite nanofiber.

[Detailed Description of the Invention]

[0001]

[Field of the Industrial Application]

The present invention relates to an electron-emitting device, an electron-emitting apparatus, an electron source and an image-forming apparatus. The present invention can be used for a display apparatus such as a television broadcast display, a display for use in a video conference system or a computer display, and for an image-forming apparatus designed as an optical printer using a photosensitive drum or the like.

[0002]

[Prior Art]

A field emission (FE) type of electron-emitting device which emits electrons from a surface of a metal when a strong electric field of 10^6 V/cm or higher is applied to the metal, and which is one of the known cold cathode electron sources, is attracting attention.

[0003]

In recent years, especially in the field of the image-forming apparatus such as a display and the like, a flat-type display using liquid crystal has come into wide use in place of a CRT. However, the flat-type display using the liquid crystal is not a selfluminous type display, and then has the problem of the necessity to have a back light, or the like. Consequently, a selfluminous type display has been desired.

[0004]

If the FE-type cold electron source is put to practical use, a thin emissive type image display apparatus can be realized. The FE-type cold electron source also contributes to reductions in power consumption and weight of an image display apparatus.

[0005]

As an example of a vertical FE-type electron-emitting device, as shown in Fig. 13, one having an emitter 135 shaped in a circular cone or a quadrangular pyramid in the substantially vertical direction from a substrate 131, for example, ones disclosed in C.A. Spindt, "Physical Properties of thin-film field emission cathodes with molybdenum cones", J. Appl. Phys., 47, 5248 (1976), and so forth (hereinafter, referred to as a “Spindt type”), has been known.

[0006]

As an example of a lateral FE structure, there is one composed of an emitter electrode having an acute extreme end, a gate electrode for drawing out electrons from the extreme end of the emitter, both formed to be parallel to a substrate, and a collector (called as an anode in the present application) configured in the direction crossing at right angles with the direction in which the gate electrode and the emitter electrode are opposed to each other (see USP 4,728,851, USP 4,904,895, IVMC91 Technical digest. P47, etc.).

[0007]

Also, Japanese Patent Application Laid-open No. 8-115652 discloses an electron-emitting device using fibrous carbon which is deposited in a narrow gap by performing thermal cracking of an organic chemical compound gas on a catalyst metal.

[0008]

[Problems to be solved by the Invention]

In an image display apparatus using one of the conventional FE-type electron sources, an electron beam spot is obtained which has a size (hereinafter referred to as "beam diameter") depending on the distance H between the electron source and the phosphor, the anode voltage Va, and the device drive voltage Vf. The beam

diameter is smaller than a millimeter and the image display apparatus has sufficiently high resolution.

[0009]

In recent years, however, there has been a tendency to require higher resolution of image display apparatuses.

[0010]

Further, with the increase in the number of display pixels, power consumption during driving due to the device capacitance of electron-emitting devices is increased. Therefore there is a need to reduce the device capacitance and the drive voltage and to improve the efficiency of electron-emitting devices.

[0011]

In the above-described Spindt type of electron source, the gate is laminated on the substrate with the insulating layer interposed therebetween, so that parasitic capacitances are produced between large gate capacitances and a multiplicity of emitters. Moreover, the drive voltage is high, several ten volts, and capacitive power consumption is disadvantageously large because of the specific structure.

[0012]

Also, since the beam of electrons drawn out immediately spreads out, there is a need for a focusing

electrode for limiting spreading of the beam. For example, Japanese Patent Application Laid-open No. 7-6714 discloses a method of converging electron trajectories by disposing an electrode for focusing electrons. This method, however, has the problem of an increase in complexity of the manufacturing process, a reduction in electron emission efficiency, etc., due to the addition of the focusing electrode.

[0013]

In ordinary lateral FE electron sources, electrons emitted from the cathode are liable to impinge on the opposed gate electrode. Therefore the structure of lateral FE electron sources has the problem of a reduction in the efficiency (the ratio of the electron current flowing through the gate and the electron current reaching the anode) and considerable spreading of the beam shape on the anode.

[0014]

Moreover, for conversing the beam of a lateral FE type electron-emitting device, as disclosed in Japanese Patent Application Laid-open No. 09-063461, the structure in which a focusing electrode is arranged on the same plane as that of an electron-emitting unit, and the like were proposed. However, these structures have the problems of the complexity of their

manufacturing method, the increase of device areas, the decrease of the efficiency of electron emission, and the like.

[0015]

In the structure in which an emitter is formed at a position nearer to an anode than to a gate in the lateral FE structure, the ratio of electric field strengths of the electric field between the anode, at which electrons finally arrive, and the emitter to the electric field between the emitter and the gate is not considered. Consequently, the structure becomes one in which emitted electrons spread.

[0016]

In view of the above-described problems, an object of the present invention is to provide an electron-emitting device in which the specific capacitance is reduced, which has a lower drive voltage, and which is capable of obtaining a finer electron beam by controlling the trajectory of emitted electrons.

[0017]

[Means for solving the Problems]

To achieve the above-described object, the present invention is an electron-emitting device forming a pair of electrodes; first voltage application

means for applying a voltage between the pair of electrodes; a cathode connected to an electrode on a lower electric potential side of the pair of electrodes electrically, the cathode having an electron-emitting member; an extraction electrode connected to an electrode on a higher electric potential side of the pair of electrodes electrically; an insulating substrate supporting the cathode and the extraction electrode so as to be opposed to each other with a gap between them; an anode arranged so as to be opposed to the substrate in parallel with the substrate, the anode receiving reached electrons emitted from the cathode; second voltage application means for applying a voltage between the anode and the cathode; and an electron-emitting portion in the electron-emitting member at a height between a plane including the extraction electrode and a plane including the anode, the device is characterized in that when the distance of the gap is d; a potential difference at a time when the first voltage application means drives the electron-emitting device is V1; a distance between the anode and the substrate is H; and an electric potential difference between the anode and the cathode is V2, the potential difference generated by the second voltage application means, then an electric field at driving $E1 = V1/d$ is

within a range from 1 to 50 times as large as an electric field $E2 = V2/H$.

[0018]

In the above-described arrangement, the place at which the electric field concentrates is limited to one side of the region where an emitter material is formed, thereby enabling emitted electrons to be first drawn out toward the extraction electrode and then made to reach the anode with no possibility of impinging on the extraction electrode. As a result, the electron emission efficiency is improved. Also, there is no possibility of scattering of electrons on the extraction electrode, so that the size of the beam spot obtained on the anode is smaller than that of the conventional beam spot of the beam scattering on the extraction electrode.

[0019]

Hereupon, each of the pair of electrodes may be formed to be integrated with either the cathode or the extraction electrode. Alternatively, the each of the pair of electrodes may be formed as an independent member.

[0020]

Moreover, it was found that, by setting the strength of the electric field between the cathode and

the extraction electrode to be the same degree as that of the electric field between the cathode and the anode, the drawn out electrons could reach the anode without impinging on the extraction electrode.

[0021]

Moreover, it is suitable that the electron-emitting member is formed on the cathode on the anode side, and that a thickness of the cathode is thicker than a thickness of the extraction electrode.

[0022]

An end of the electron-emitting member on the extraction electrode may be formed to be located in the gap.

[0023]

Moreover, the electron-emitting device may be configured in order that the electron-emitting member may be formed on the cathode on the anode side, and that the substrate may have a difference in level between the extraction electrode and the cathode, and further that the cathode may be positioned to be closer to the anode than to the extraction electrode with the difference in level located between them.

[0024]

Moreover, it is suitable that the electron-emitting member is made of a material containing carbon

as a main ingredient.

[0025]

Moreover, it is suitable that the material containing carbon as a main ingredient is an aggregate of fibrous carbon.

[0026]

By using the fibrous carbon as the material of the electron-emitting member, it was made to be possible to take out electrons in a very low electric field.

[0027]

Moreover, it is suitable that the aggregate of the fibrous carbon comprises a graphite nanofiber, a carbon nanotube, amorphous carbon, all grown up through catalyst particles, or a mixture of these materials.

[0028]

Moreover, it is suitable that the catalyst particles are made of Pd, Ni, Fe, Co or an alloy of these substances.

[0029]

Moreover, the present invention is an electron source characterized by at least a device row made by arranging a plurality of the electron-emitting devices in parallel to connect the arranged electron-emitting device.

[0030]

Moreover, the present invention is an electron source characterized by at least a device row made by arranging a plurality of the electron-emitting devices, and wiring to drive the devices is arranged in a matrix.

[0031]

Moreover, the present invention is an image-forming apparatus characterized by the electron source, a fluorescent substance as the anode, and a mechanism for controlling an electron quantity of each electron-emitting device by means of an information signal.

[0032]

Moreover, the present invention is a manufacturing method of an electron-emitting device, the method characterized by the steps of: forming a pair of electrodes formed on an insulating substrate with a gap between them; forming metal oxide particles connected to either of the pair of electrodes electrically; performing reduction coagulation of the metal oxide particles to be metal particles; and growing fibrous carbon on the metal particles.

[0033]

Moreover, the present invention is an electron-emitting device including a first electrode and a

second electrode disposed on a surface of a substrate with a gap formed between the first electrode and the second electrode; the device forming an electric field substantially parallel to the surface of the substrate by applying electric potential higher than that of the first electrode to the second electrode, the device emitting electrons, the device characterized in that a plurality of columnar substances containing carbon as a main ingredient is arranged on the first electrode.

[0034]

Moreover, a material more effective in accelerating deposition of the carbon than a material of the first electrode may be provided between the columnar substances containing the carbon as the main ingredient and the first electrode.

[0035]

Moreover, the material effective in accelerating the deposition of the carbon is one comprising Pd, Ni, Fe, Co or an alloy formed of the substances.

[0036]

Moreover, the material effective in accelerating the deposition of the carbon is provided in a form of a plurality of particles on the first electrode.

[0037]

Moreover, the plurality of particles may be

provided on the first electrode at a density of 10^{10} particles/cm^2 or higher.

[0038]

Moreover, it is suitable that a thickness of the first electrode is thicker than the thickness of the second electrode.

[0039]

Moreover, it is suitable that the columnar substances containing the carbon as the main ingredient are ones selected in a group of carbon nanotube and a graphite nanofiber.

[0040]

Moreover, the present invention is an electron-emitting apparatus including an electron-emitting device and a substantially plane-like anode electrode arranged to be opposed to the electron-emitting device, the apparatus characterized in that the electron-emitting device is the one described above.

[0041]

Moreover, it is suitable that a distance between the anode electrode and a surface of the first electrode is shorter than a distance between the anode electrode and a surface of the second electrode.

[0042]

Moreover, it is suitable that distances between

the anode electrode and ends of the columnar substances containing the carbon as the main ingredient on a side at which the columnar substances are not connected to the first electrode are shorter than a distance between the anode electrode and the surface of the second electrode.

[0043]

Moreover, the present invention is an electron-emitting apparatus comprising: a first electrode including an electron-emitting member, and a second electrode for extracting electrons from the electron-emitting member; first electric potential application means for applying to the second electrode electric potential higher than electric potential applied to the first electrode; a substrate including the first and the second electrodes on a surface of the substrate so as to oppose the first and the second electrodes to each other with a gap; an anode electrode including a surface parallel to the surface of the substrate substantially, the anode electrode disposed with a distance from the substrate; and second electric potential application means for applying to the anode electric potential higher than electric potential applied to the second electrode, the apparatus characterized in that a plane containing a part of a

surface of the electron-emitting member, the plane substantially parallel to the surface of the substrate, is positioned at a position between a plane containing a part of a surface of the extraction electrode, the plane substantially parallel to the surface of the substrate, and the surface of the anode electrode.

[0044]

Moreover, it is suitable that, when a distance between the first electrode and the second electrode is d; a difference between the electric potential applied to the first electrode and the electric potential applied to the second electrode, both potential applied by the first electric potential application means, is V1; the distance between the surface of the anode electrode and the surface of the substrate is H; and a difference between the electric potential applied to the anode by the second electric potential application means and the electric potential applied to the first electrode is V2, then an electric field E1 = V1/d is within the range from 1 to 50 times as large as an electric field E2 = V2/H.

[0045]

Moreover, the electron-emitting member may be made of a plurality of columnar substances containing carbon as a main ingredient.

[0046]

Moreover, a material more effective in accelerating deposition of the carbon than the material of the first electrode may be provided between the columnar substances containing the carbon as the main ingredient and the first electrode.

[0047]

Moreover, the material effective in accelerating deposition of the carbon may be one comprising Pd, Ni, Fe, Co or an alloy formed of the materials.

[0048]

Moreover, the material effective in accelerating deposition of the carbon may be provided in the form of a plurality of particles on the first electrode.

[0049]

Moreover, the plurality of particles may be provided on the first electrode at a density of 10^{10} particles/cm^2 or higher.

[0050]

Moreover, it is suitable that the thickness of the first electrode is thicker than the thickness of the second electrode.

[0051]

Moreover, it is suitable that the columnar substances containing the carbon as the main ingredient

are ones selected in a group of carbon nanotube and a graphite nanofiber.

[0052]

[Embodiments of the Invention]

Preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings. The description of components of the embodiments made below with respect to the size, material and shape of the components and the relative positions of the components is not intended to limit the scope of the present invention except for particular mention of specified details.

[0053]

The operating voltage Vf of FE devices is generally determined by the electric field at an extreme end of an emitter obtained from the Poisson equation and by the current density of electron emission current according to the relational expression called "Fowler-Nordheim equation" with a work function of the electric field and the emitter portion used as a parameter.

[0054]

A stronger electric field is obtained as the electric field necessary for emission of electrons as the distance D between the emitter extreme end and the

gate electrode is smaller or the radius r of the emitter extreme end is smaller.

[0055]

On the other hand, the maximum size Xd in the X-direction of the electron beam obtained on the anode (e.g., the maximum reach from the center of the circular beam shape 137 shown in Fig. 13) is expressed in such a form as to be proportional to (Vf/Va) in simple calculation.

[0056]

As is apparent from this relationship, an increase in Vf results in an increase in beam diameter.

[0057]

Consequently, there is a need to minimize the distance D and the radius of curvature r in order to reduce Vf.

[0058]

Beam shapes in conventional arrangements will be described with reference to Figs. 13 and 14. In Figs. 13 and 14, substrates which are corresponding components of the two arrangements are indicated by 131 and 141; emitter electrodes by 132 and 142; insulating layers by 133 and 143.

[0059]

In the case of the Spindt type described above

with reference to Fig. 13, when Vf is applied between the emitter 135 and the gate 134, the strength of the electric field at the extreme end of the projection of the emitter 135 is increased and electrons are thereby taken out of a conical emitter portion about the extreme end into the vacuum.

[0060]

The electric field at the extreme end of the emitter is formed based on the shape of the extreme end of the emitter to have a certain finite area on the same, so that electrons are perpendicularly drawn out from the finite emitter extreme end area according to the potential.

[0061]

Simultaneously, other electrons are emitted at various angles. Electrons emitted at larger angles are necessarily drawn toward the gate.

[0062]

As a result, if the gate is formed so as to have a circular opening, the distribution of electrons on the anode 136 shown in Fig. 13 forms a substantially circular beam shape 137. That is, the shape of the beam obtained is closely related to the shape of the drawing gate and to the distance between the gate and the emitter.

[0063]

As the prior art in which electrons are drawn out along one direction, there is a lateral FE structure as shown in Fig. 14.

[0064]

In Fig. 14, 141 is a substrate. 142 is an emitter electrode. 143 is an insulator layer. 144 is a gate. 145 is an emitter. Incidentally, an anode 146 is disposed on a substrate opposed to the substrate 141 on which the emitter 145 and the gate 144 are mounted.

[0065]

In the arrangement shown in Fig. 14, a very strong electric field (a lateral electric field) which is substantially parallel to the surface of the substrate 141 is generated between the emitter 145 and the gate 144. As a result, among the electrons emitted from the emitter 145, a part 149 of them is taken out in the vacuum, and the other electrons are taken in by the gate electrode 144.

[0066]

In the arrangement shown in Fig. 14, electric field vectors toward the anode 146 differ in direction from those causing emission of electrons (the electric field from the emitter 145 toward the gate 144). Therefore the distribution of electrons (beam spot)

formed by emitted electrons on the anode 146 is increased.

[0067]

The electric field of electrons drawn out (referred to as "lateral electric field" in the following description for convenience sake while the electric field strengthening effect of the emitter configuration is ignored) and the electric field toward the anode (referred to as "vertical electric field" in the following description) will further be described.

[0068]

As described above, electrons emitted from the emitter are first drawn out by the lateral electric field, fly toward the gate, and are then moved upward by the vertical electric field to reach the anode.

[0069]

Important factors of this effect are the ratio of the strengths of the lateral and vertical electric fields and the relative position of the electron emission point.

[0070]

When the lateral electric field is stronger than the vertical electric field by an order of magnitude, the trajectories of almost all of electrons drawn out from the emitter are gradually bent by radial potential

produced by the lateral electric field so that the electrons fly toward the gate. A part of the electrons impinging on the gate ejects again in a scattering manner. After ejection, however, the electrons repeat scattering while spreading out along the gate by forming elliptical trajectories again and again and while being reduced in number when ejecting until they are caught by the vertical electric field. Only after the scattered electrons have exceeded an equipotential line formed by the gate potential (which line may be called "stagnation point"), they are moved upward by the vertical electric field.

[0071]

When the lateral electric field and the vertical electric field are approximately equal in strength, the restraint imposed by the lateral electric field on electrons drawn out is reduced, although the trajectories of the electrons are bent by the radial potential. In this case, therefore, electron trajectories appear along which electrons travel to be caught by the vertical electric field without impinging on the gate.

[0072]

It has been found that if the electron emission position at which electrons are emitted from the

emitter is shifted from the gate plane toward the anode plane (see Fig. 6), emitted electrons can form trajectories such as to be caught by the vertical electric field with no possibility of impinging on the gate when the lateral electric field and the vertical electric field are approximately equal in strength, that is, the ratio of the strength of the lateral electric field to that of the vertical electric field is 1 to 1.

[0073]

Also, a study made of the electric field ratio has shown that if the distance between the gate electrode 144 and the extreme end of the emitter electrode 145 is d; the potential difference (between the gate electrode and the emitter electrode) when the device is driven is V1; the distance between the anode and the substrate (element) is H; and the potential difference between the anode and the cathode (emitter electrode) is V2, a trajectory along which electrons drawn out impinge on the gate is formed when the lateral electric field $E1 = V1/d$ is 50 times or more stronger than the vertical electric field $E2 = V2/H$.

[0074]

The inventor of the present invention has also found that a height s (defined as the distance between

a plane containing a portion of a gate electrode 2 surface and substantially parallel to a substrate 1 surface and a plane containing an electron-emitting member 4 surface and substantially parallel to the substrate 1 surface (see Fig. 6)) can be determined such that substantially no scattering occurs on the gate electrode 2. The height s depends on the ratio of the vertical electric field and the lateral electric field (vertical electric field strength/lateral electric field strength). As the vertical-lateral electric field ratio is lower, the height s is lower. AS the lateral electric field is stronger, the necessary height s is higher.

[0075]

The height set in a practical manufacturing process ranges from 10 nm to 10 μm.

[0076]

In the conventional arrangement, the gate and the emitter are formed flush with each other along a common plane and the lateral electric field is stronger than the vertical electric field by an order of magnitude, so that there is a considerable tendency to reduce, by impingement on the gate, the amount of electrons drawn out into the vacuum.

[0077]

Further, in the conventional arrangement, the thickness and the width of the gate electrode, and relative positions of the gate, the emitter and the anode are determined so as to increase the strength of the electric field in the lateral direction, so that the electron distribution on the anode spreads widely.

[0078]

As described above, to restrict the distribution of electrons reaching the anode, it is necessary (1) to reduce Vf, (2) to unidirectionally draw out electrons, (3) to consider the trajectory of electrons and, if scattering on the gate occurs, (4) to consider the electron scattering mechanism (elastic scattering in particular).

[0079]

The arrangement of the present invention was zealously examined on the basis of the thought described above with the aim of providing an electron-emitting device in which the distribution of electrons is made finer, and in which the efficiency is improved.

[0080]

The electron-emitting device in accordance with the present invention described above will now be described below in detail by means of the preferred embodiments.

[0081]

Fig. 1(a) is a schematic plan view showing an example of an electron-emitting device in accordance with the present invention. Fig. 1(b) is a cross-sectional view taken along the line A-A of Fig. 1(a). Fig. 6 is schematic view of an arrangement in a state where the electron-emitting apparatus of the present invention is driven.

[0082]

In Figs. 1 and 6 are illustrated an insulating substrate 1, an extraction electrode 2 (also referred to as "gate electrode" or "second electrode"), a cathode electrode 3 (also referred to as "first electrode"), a cathode (emitter) material 4 provided on the cathode 3 (also referred to as " electron-emitting member").

In the device of the present invention, on the basis of the knowledge described above, if as shown in Fig. 6 the distance by which the emitter electrode (cathode electrode) 3 and the gate electrode (extraction electrode) 2 are spaced apart from each other is d; the potential difference (the voltage between the emitter electrode 3 and the gate electrode 2) when the electron-emitting device is driven is Vf; the distance between the anode 61 and the surface of

the substrate 1 on which the electron-emitting device is arranged is H; and the potential difference between the anode electrode 61 and the emitter electrode 3 is Va, an electric field produced to drive the device: E1 = Vf/d is set within the range from 1 to 50 times as large as E2 = Va/H, both inclusive. The proportion of electrons impinging on the gate electrode 2 in electrons emitted from the emitter electrode side is reduced thereby. In this manner, a high-efficiency electron-emitting device capable of preventing an emitted electron beam from spreading out widely can be obtained.

[0083]

Further, in the electron-emitting device of the present invention, the electron-emitting member 4 is placed at a height s (defined as the distance between the plane containing a portion of the surface of gate electrode 2 and substantially parallel to the surface of substrate 1 and the plane containing the surface of electron-emitting member 4 and substantially parallel to the surface of substrate 1 (see Fig. 6)) such that no scattering occurs on the gate electrode 2. The height s depends on the ratio of the vertical electric field and the lateral electric field (vertical electric field strength/lateral electric field strength). As

the vertical-lateral electric field ratio is lower, the height s is lower. As the lateral electric field is stronger, the necessary height s is higher. Practically, the height is not less than 10 nm not more than 10 μm.

[0084]

Examples of the insulating substrate 1 are the following substrates whose surfaces are sufficiently cleansed: quartz glass; glass in which the content of an impurity such as Na is reduced by partial substitution by K, for example; a laminate formed in such a manner that SiO_2 is laminated by sputtering or the like on soda lime glass, a silicon substrate or the like; and an insulating substrate made of a ceramic such as alumina.

[0085]

Each of the extraction electrode 2 and cathode 3 is an electrically conductive member formed on the surface of the substrate 1 by an ordinary vacuum film forming technique, such as evaporation or sputtering, or a photolithography technique so as to face each other. The material of the electrodes 2 and 3 is selected from, for example, carbon, metals, nitrides of metals, carbides of metals, borides of metals, semiconductors, and metallic compounds of

semiconductors. The thickness of the electrodes 2 and 3 is set within the range from several ten nanometers to several ten microns. Preferably, the material of the electrodes 2 and 3 is a heat resistant material formed of carbon, a metal, a nitride of a metal or a carbide of a metal.

[0086]

In particular, in the case of growth of fibrous carbon described below, the electrodes are preferably formed of silicon having conductivity, e.g., doped polysilicon or the like.

[0087]

If there is apprehension about, for example, a voltage drop due to the small thickness of the electrodes, or if a plurality of the electron-emitting devices are used in matrix form, a low-resistance wiring metallic material may be used to form suitable wiring portions on condition that it does not affect emission of electrons.

[0088]

The emitter material (electron-emitting member) 4 may be formed in such a manner that a film deposited by an ordinary vacuum film forming method such as sputtering is worked into the shape of the emitter by using a technique such as reactive ion etching (RIE).

Alternatively, it may be formed by growing needle crystals or whiskers by seed growth in chemical vapor deposition (CVD). In the case of RIE, the control of the emitter shape depends on the kind of the substrate used, the kind of gas, the gas pressure (flow rate), the etching time, the energy for forming plasma, etc. In a CVD forming process, the emitter shape is controlled by selecting the kind of the substrate, the kind of gas, the flow rate, the growth temperature, etc.

[0089]

Examples of the material used to form the emitter (electron-emitting member) 4 are carbides, such as TiC, ZrC, HfC, TaC, SiC, and WC, amorphous carbon, graphite, diamondlike carbon, carbon containing dispersed diamond, and carbon compounds. According to the present invention, fibrous carbon is particularly preferably used as the material of the emitter (electron-emitting member) 4. "Fibrous carbon" referred to in the description of the present invention can also be expressed as "material in columnar form containing carbon as a main constituent" or "material in filament form containing carbon as a main constituent". Further, "fibrous carbon" can also be expressed as "fibers containing carbon as a main

constituent". More specifically, "fibrous carbon" in accordance with the present invention comprises carbon nanotubes, graphite nanofibers, and amorphous carbon fibers.

[0090]

The gap between the extraction electrode 2 and the cathode 3 and the drive voltage may be determined so that the value of the lateral electric field necessary for emission of electrons from the cathode material used is 1 to 50 times larger than that of the vertical electric field necessary for forming an image, as described above.

[0091]

In a case where a light-emitting member such as a phosphor is provided on the anode, the necessary vertical electric field is, preferably, within the 10^{-1} to 10 V/μm range. For example, in a case where the gap between the anode and the cathode is 2 mm and 10 kV is applied between the anode and the cathode, the vertical electric field is 5 V/μm. In this case, the emitter material (electron-emitting member) 4 to be used has an electron-emitting electric field value of 5 V/μm or higher. The gap and the drive voltage may be determined in correspondence with the selected electron-emitting electric field value.

[0092]

An example of a material having an electric field threshold of several V/μm is fibrous carbon, which is produced by cracking carbon hydride gas by the use of a catalyst (a material which promotes the deposition of carbon) (see Figs. 11 and 12). Each of Figs. 11 and 12 shows an example of the configuration of fibrous carbon. In each of Figs. 11 and 12, the configuration is schematically shown at the optical microscope level (to 1,000 times) in the left-hand section, at the scanning electron microscope level (to 30,000 times) in the middle section, and at the transmission electron microscope level (to 1,000,000 times) in the right-hand section.

[0093]

A graphene structure formed into a cylinder is called a carbon nanotube (a multilayer cylindrical graphene structure is called a multiwall nanotube). Its threshold value is minimized when the tube end is opened.

[0094]

The fibrous carbon shown in Fig. 12 may be produced at a comparatively low temperature by the use of a catalyst like a carbon nanotube. Fibrous carbon having such a configuration is composed of a graphene

layered body (thus, it may be referred to as "graphite nanofiber", and has an amorphous structure whose ratio is increased with temperature).

[0095]

The carbon nanotube and the graphite nanofiber are different from each other in the kinds of catalysts and in the temperatures of cracking. There are the case where the material having both the structures of the carbon nanotube and the graphite nanofiber can be selected by the use of the same catalyst according to a temperature, and the case where only either of the two structures can be obtained.

[0096]

Each type of fibrous carbon has an electron emission threshold value of about 1 to 10 V/μm and is therefore preferred as the material of the emitter (electron-emitting member) 4 in accordance with the present invention.

[0097]

Fe, Co or the like is used for forming the carbon nanotube as the catalyst material. However, Pd or Ni can be used as a seed for forming carbon.

[0098]

In particular, if Pd or Ni is used, graphite nanofibers can be formed at a low temperature (not

lower than 400°C). The necessary carbon nanotube forming temperature in the case of using Fe or Co is 800°C or higher. Also, the process of producing a graphite nanofiber material by using Pd or Ni, which can be performed at a lower temperature, is preferred from the viewpoint of reducing the influence on other components and limiting the manufacturing cost.

[0099]

Further, the characteristic of Pd that resides in enabling oxides to be reduced by hydrogen at a low temperature (room temperature) may be utilized. That is, palladium oxide may be used as a seed forming material.

[0100]

If hydrogen reduction using palladium oxide is performed, an initial agglomeration seed can be formed at a comparatively low temperature (equal to or lower than 200°C) without metallic film thermal agglomeration or ultrafine particle forming/deposition conventionally used as ordinary seed forming techniques.

[0101]

The above-mentioned hydrocarbon gas may be, for example, acetylene, ethylene, methane, propane, or propylene. Further, CO or CO_2 gas or vapor of an organic solvent such as ethanol or acetone may be used

in some case.

[0102]

As shown in FIG. 1, the electron-emitting point in the emitter (electron-emitting member) 4 is conjectured to exist at the position nearest to the gate, but the region where the emitter (electron-emitting member) exists will be referred to as "emitter region" regardless of contribution to emission of electrons.

[0103]

The position of the electron emission point (electron-emitting portion) in the "emitter region" and the electron-emitting operation will be described with reference to Figs. 6 and 7.

[0104]

The present device having a gap (the distance between the cathode electrode 3 and the extraction electrode 2) of several microns was set in a vacuum apparatus 60 such as shown in Fig. 6. A sufficiently high degree of vacuum about 10^{-4} Pa was produced by a evacuating pump 65. A high voltage Va of several kilovolts was applied from a high voltage source ("second voltage application means" ("second potential application means")) to the anode 61, which was placed so that the surface of the anode (anode electrode) 61

is at the height H, which was several millimeters, from the surface of the substrate 1, as shown in Fig. 6. The substrate 1 and the anode 61 were positioned relative to each other so that their surfaces are parallel to each other.

[0105]

Between the cathode 3 and the extraction electrode 2 of the electron-emitting device, a pulse voltage of about several ten volts was applied as drive voltage Vf from a power supply (not shown) ("first voltage application means" ("first potential application means")). Flowing device current If and electron emission current Ie were measured.

[0106]

It is supposed that, during this operation, equipotential lines 63 are formed as shown in Fig. 6 (an electric field (the direction of an electric field) substantially parallel to the surface of the substrate 1, and that the concentration of the electric field is maximized at the point on a portion of the electron-emitting member 4 closest to the anode and facing the gap, as indicated by 64. It is thought that electrons are emitted mainly from the portion of the electron-emitting material in the vicinity of this electric field concentration point, where the concentration of

the electric field is maximized. An Ie characteristic such as shown in Fig. 7 was obtained. That is, Ie rises abruptly at a voltage about half the applied voltage. The If characteristic (not shown) was similar to the Ie characteristic but the value of If was sufficiently smaller than that of Ie.

[0107]

In the following, on the basis of this principle, an image-forming apparatus obtained by arranging a plurality of the electron-emitting devices to which the present invention can be applied will be described with reference to Fig. 8. In Fig. 8 are illustrated an electron source substrate 81, X-direction wiring 82, Y-direction wiring 83, electron-emitting device 84 in accordance with the present invention, and a connecting conductor 85.

[0108]

X-direction wiring 82 has m conductors DX1, DX2, ... DXm, which may be constituted by, for example, a conductive metal formed by vacuum evaporation, printing, sputtering, or the like. The material, film thickness, and width of the wiring are selected according to a suitable design. Y-direction wiring 83 has n conductors DY1, DY2, ... DYn and is formed in the same manner as X-direction wiring 82. An interlayer

insulating layer (not shown) is provided between the m conductors of X-direction wiring 82 conductors and the n conductors of Y-direction wiring 83 to electrically separate these conductors (each of m and n is a positive integer).

[0109]

The interlayer insulating layer (not shown) is, for example, a SiO_2 layer formed by vacuum evaporation, printing, sputtering, or the like. For example, the interlayer insulating film is formed in the desired shape over the whole or part of the surface of the substrate 81 on which X-direction wiring 82 has been formed and the film thickness, material and fabrication method are selected to ensure withstanding against the potential difference at the intersections of the conductors of X-direction wiring 82 and Y-direction wiring 83 in particular. The conductors of X-direction wiring 82 and Y-direction wiring 83 are respectively extended outward as external terminals.

[0110]

Pairs of electrodes (not shown) constituting electron-emitting devices 84 are electrically connected to the m conductors of X-direction wiring 82 and the n conductors of Y-direction wiring 83 by connecting conductors 85 made of a conductive metal or the like.

[0111]

The materials forming wiring 82 and wiring 83, the material forming the connecting conductors 85 and the materials forming the pairs of device electrodes may be entirely constituted of common constituent elements or partially constituted of common constituent elements, or may be constituted of different constituent elements. These materials are selected from, for example, the above-described device electrode materials. If the materials of the device electrodes and the wiring materials are the same, the wiring conductors connected to the device electrodes can be considered to be device electrodes.

[0112]

A scanning signal application means (not shown) for applying scanning signals for selecting the rows of electron-emitting devices 84 arranged in the X-direction is connected to X-direction wiring 82. On the other hand, a modulation signal generation means for modulating voltages applied to the columns of electron-emitting devices 84 arranged in the Y-direction according to input signals is connected to Y-direction wiring 83. The drive voltage applied to each electron-emitting device is supplied as a voltage corresponding to the difference between the scanning

signal and the modulation signal applied to the element.

[0113]

In the above-described arrangement, each device can be selected by using the passive-matrix wiring to be driven independently.

[0114]

An image forming apparatus constructed by using an electron source having such a passive matrix array will be described with reference to Fig. 9. Fig. 9 schematically shows an example of the display panel of the image forming apparatus. Referring to Fig. 9, a plurality of electron-emitting devices is disposed on an electron source substrate 81, which is fixed on a rear plate 91. A face plate 96 has a glass substrate 93, a phosphor film 94 provided as a light emitting member on the internal surface of the glass substrate 93, a metal back (anode) 95, etc. The rear plate 91 and the face plate 96 are connected to a supporting frame 92 by using frit glass or the like. An envelope 97 is formed by being seal-bonded by baking in, for example, atmospheric air, a vacuum or in nitrogen in the 400 to 500°C temperature range for 10 minutes or longer.

[0115]

The envelope 97, as described above, is constituted by the face plate 96, the supporting frame 92, and the rear plate 91. The rear plate 91 is provided mainly for the purpose of reinforcing the substrate 81. If the substrate 81 itself has sufficiently high strength, there is no need to separately provide the rear plate 91. That is, the supporting frame 92 may be directly seal-bonded to the substrate 81 and the envelope 97 may be formed by the frame plate 96, the supporting frame 92 and the substrate 81. A supporting member (not shown) called a spacer may be provided between the face plate 96 and the rear plate 91 to enable the envelope 97 to have a sufficiently high strength for resisting atmospheric pressure.

[0116]

[Examples]

Examples of the present invention will be described below in detail.

[0117]

(Example 1)

Fig. 1(a) shows a top view of an electron-emitting device fabricated in this embodiment. Fig. 1(b) is a cross-sectional view taken along the line A-A of Fig. 1(a).

[0118]

Fig. 1 illustrates an insulating substrate 1, an extraction electrode 2 (gate), a cathode 3, and a cathode (emitter) material 4.

[0119]

The process of fabricating the electron-emitting device of this embodiment will be described in detail.

(Step 1)

A quartz substrate was used as substrate 1. After sufficiently cleansing the substrate, a 5 nm thick Ti film (not shown) and a 30 nm thick poly-Si film (arsenic doped) were successively deposited by sputtering on the substrate as gate electrode 2 and cathode (emitter) electrode 3.

[0120]

Next, a resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

[0121]

Thereafter, dry etching was performed on the poly-Si (arsenic doped) layer and Ti layer with the patterned photoresist used as a mask, CF_4 gas being used to etch the Ti layer. An extraction electrode 2 and a cathode 3 having a gap of 5 μm therebetween were thereby formed (Fig. 5(a)).

[0122]

(Step 2)

Next, a Cr having a thickness of about 100 nm was deposited on the entire substrate by electron beam (EB) evaporation.

[0123]

A resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

[0124]

An opening corresponding to a region (100 μm square) where electron-emitting material was to be provided was formed on the cathode 3 with the patterned photoresist used as a mask. Cr at the opening was removed by using a cerium nitrate etching solution.

[0125]

After removing the resist, a complex solution prepared by adding isopropyl alcohol, etc., to a Pd complex was applied to the entire substrate by spin coating.

[0126]

After application of the solution, a heat treatment was performed in atmospheric air at 300°C to form a palladium oxide layer 51 having a thickness of about 10 nm. Thereafter, Cr was removed by using a

cerium nitrate etching solution (Fig. 5(b)).

[0127]

(Step 3)

The substrate was baked at 200°C, atmospheric air was evacuated, and a heat treatment was then performed in 2% hydrogen flow diluted with nitrogen. At this stage, particles 52 having a diameter of about 3 to 10 nm were formed on the surface of the device. The density of the particles at this stage was estimated at about 10^{11} to 10^{12} particles/cm^2 (Fig. 5(c)).

[0128]

(Step 4)

Subsequently, a heat treatment was performed in a 0.1% ethylene flow diluted with nitrogen at 500°C for 10 minutes. The state after the heat treatment was observed with a scanning electron microscope to find that a multiplicity of fibrous carbon having a diameter of about 10 to 25 nm and extending like fibers while curving or bending had been formed in the Pd-coated region. The thickness of the fibrous carbon layer was about 500 nm (Fig. 5(d)).

[0129]

This electron-emitting device was set in the vacuum apparatus 60 shown in Fig. 6. A sufficiently high vacuum of about 2×10^{-5} Pa was produced by the

evacuating pump 62. Voltage Va = 10 kV was applied as anode voltage to the anode 61 distanced by H = 2 mm from the device, as shown in Fig. 6. Also, a pulse voltage of Vf = 20 V was applied as drive voltage to the device. Device current If and electron emission current Ie thereby caused were measured.

[0130]

The If and Ie characteristics of the electron-emitting device were as shown in Fig. 7. That is, Ie rises abruptly at a voltage about half the applied voltage, and a current of about 1 μA was measured as electron emission current Ie at a Vf value of 15 V. On the other hand, the If characteristic was similar to the Ie characteristic but the value of If was smaller than that of Ie by an order of magnitude or more.

[0131]

The obtained beam had a generally rectangular shape having a longer side along the Y-direction and a shorter side in the X-direction. The beam width was measured with respect to different gaps of 1 μm and 5 μm while Vf was fixed at 15 V and the distance H to the anode was fixed at 2 mm. Table 1 shows the results of this measurement.

[0132]

Table 1

	Va = 5 kV	Va = 10 kV
Gap: 1 μm	60 μm in x-direction 170 μm in y-direction	30 μm in x-direction 150 μm in y-direction
Gap: 5 μm	93 μm in x-direction 170 μm in y-direction	72 μm in x-direction 150 μm in y-direction

[0133]

It was possible to change the necessary electric field for driving by changing the growth conditions. In particular, the average particle size of Pd particles formed by reduction of palladium oxide is related to the diameter of fibers thereafter grown. It was possible to control the average Pd particle size through the Pd density in the Pd complex coating and the rotational speed of spin coating.

[0134]

The fibrous carbon of this electron-emitting device was observed with the transmission electron microscope to recognize a structure in which graphenes are layered, as shown in the right-hand section of Fig. 12. The graphene stacking intervals (in the Z-axis direction) resulting from heating at a lower temperature, about 500°C were indefinite and was 0.4 nm. As the heating temperature was increased, the grating intervals became definite. The intervals resulting from heating at 700°C were 0.34 nm, which is close to 0.335 nm in graphite.

[0135]

(Example 2)

Fig. 2 shows a second example of the present invention.

[0136]

In this example, an electron-emitting device was fabricated in the same manner as that in the first example except that the cathode 3 corresponding to that in the first embodiment had a thickness of 500 nm and fibrous carbon provided as electron-emitting material had a thickness of 100 nm. Currents If and Ie in the fabricated electron-emitting device were measured.

[0137]

In this device arrangement, the electron emission point was positively heightened (toward the anode) relative to the gate electrode by increasing the thickness of the cathode 3. Trajectories along which electrons impinge on the gate were thereby reduced, thereby preventing a reduction in efficiency and occurrence of a beam-thickening phenomenon.

[0138]

Also in this device arrangement, the electron emission current Ie at Vf = 20V was about 1 μA. On the other hand, the If characteristic was similar to the Ie characteristic but the value of If was smaller than

that of Ie by two orders of magnitude.

[0139]

The results of measurement of the beam diameter in this embodiment were substantially the same as those shown in Table 1.

[0140]

(Example 3)

Fig. 3 shows a third example of the present invention.

[0141]

The present example shows the case where, in the step corresponding to step 2 in the first example, palladium oxide 51 was provided over the gap and the electrode 3 at almost the midpoint in the gap (about a half of the distance of the gap). The present example is the same as the first example in the following steps 3 and 4.

[0142]

The electric field in the electron-emitting device of this example was twice as strong as that in the first example because the gap was reduced, thereby enabling the drive voltage to be reduced to about 8 V.

[0143]

(Example 4)

Fig. 4 shows a fourth example of the present

invention. In this example step 1 and step 2 described above with respect to the first embodiment were changed as described below.

[0144]

(Step 1)

A quartz substrate was used as substrate 1. After sufficiently cleansing the substrate, a 5 nm thick Ti film and a 30 nm thick poly-Si film (arsenic doped) were successively deposited by sputtering on the substrate as cathode (emitter) electrode 3.

[0145]

Next, a resist pattern was formed by photolithography using a positive photoresist (AZ1500/ from Clariant Corporation).

[0146]

Next, dry etching was performed on the poly-Si layer and Ti layer by using CF_4 gas, with the patterned photoresist used as a mask. Cathode 3 was thereby formed.

[0147]

The quartz substrate was then etched to a depth of about 500 nm by using a mixed acid formed of hydrofluoric acid and ammonium fluoride.

[0148]

Subsequently, a 5 nm thick Ti film and a 30 nm

thick Pt film were successively deposited on the substrate as gate electrode 2 by again performing sputtering. After removing the photoresist from the cathode, a resist pattern was again formed by using a positive photoresist (AZ1500/ from Clariant Corporation) to form the gate electrode.

[0149]

Next, dry etching was performed on the Pt layer and Ti layer by using Ar, with the patterned photoresist used as a mask. Electrode 2 was thereby formed so that the step formed between the electrodes functions as a gap.

[0150]

Next, a resist pattern was formed on the cathode, a Ni film having a thickness of about 5 nm was formed by resistance heating evaporation having a good straight-in effect, and oxidation was thereafter performed at 350°C for 30 minutes.

[0151]

This step was followed by the same steps as those in the first example.

[0152]

The above-described device arrangement enabled formation of a finer gap such that electrons were effectively emitted at a lower voltage of about 6 V.

[0153]

Because the height of the electron-emitting material (film thickness) was thick, electrons were drawn out not only from the upper portion of the film but also from an intermediate portion. Thus, the arrangement in this embodiment has the effect of preventing a reduction in efficiency due to impingement of electrons on the gate electrode and occurrence of a beam-thickening phenomenon.

[0154]

(Example 5)

An image-forming apparatus obtained by arranging a plurality of the electron-emitting devices to which the present invention can be applied will be described with reference to Figs. 8, 9, and 10. In Fig. 8 are illustrated an electron source substrate 81, X-direction wiring 82, Y-direction wiring 83, electron-emitting devices 84 in accordance with the present invention, and connecting conductors 85.

[0155]

The matrix wiring shown in Fig. 8, in which the device capacitance is increased by arranging a plurality of electron-emitting devices, has a problem that, even when a short pulse produced by pulse-width modulation is applied, the waveform is dulled or

distorted by capacitive components to cause failure to obtain the necessary grayscale level, for example. In this example, therefore, a structure was adopted in which an interlayer insulating layer designated by 91 in FIG. 9 was provided by the immediate side of the electron-emitting region as shown in the first embodiment to limit the increase in capacitive components in regions other than the electron-emitting region.

[0156]

Referring to Fig. 8, X-direction wiring 82 has m conductors DX1, DX2, ... DXm, which has a thickness of about 1 μm and a width of 300 μm, and which is formed of an aluminum wiring material by evaporation. The material, film thickness, and width of the wiring conductors are selected according to a suitable design. Y-direction wiring 83 has n conductors DY1, DY2, ... DYn, which has a thickness of 5 μm and width of 100 μm, and which is formed in the same manner as X-direction wiring 82. An interlayer insulating layer (not shown) is provided between the m conductors of X-direction wiring 82 and the n conductors of Y-direction wiring 83 to electrically separate these conductors (each of m and n is a positive integer).

[0157]

The interlayer insulating layer (not shown) was, for example, a SiO_2 layer formed by sputtering or the like and having a thickness of about 0.8 μm. For example, the interlayer insulating film was formed in the desired shape over the whole or part of the surface of the substrate 81 on which X-direction wiring 82 had been formed. Specifically, the thickness of the interlayer insulating film was determined so as to ensure withstanding against the potential difference at the intersections of the conductors of X-direction wiring 82 and Y-direction wiring 83, and so that the device capacitance per device was 1 pF or less and the withstanding voltage was 30 V. The conductors of X-direction wiring 82 and Y-direction wiring 83 were respectively extended outward as external terminals.

[0158]

Pairs of electrodes (not shown) constituting electron-emitting devices 84 are electrically connected to the m conductors of X-direction wiring 82 and the n conductors of Y-direction wiring 83 by connecting conductors 85 made of a conductive metal or the like.

[0159]

A scanning signal application means (not shown) for applying scanning signals for selecting the rows of electron-emitting devices 84 arranged in the X-

direction is connected to X-direction wiring 82. On the other hand, a modulation signal generation means for modulating voltages applied to the columns of electron-emitting devices 84 arranged in the Y-direction according to input signals is connected to Y-direction wiring 83. The drive voltage applied to each electron-emitting device is supplied as a voltage corresponding to the difference between the scanning signal and the modulation signal applied to the element. In the present invention, Y-direction wiring was connected to be high potential, while X-direction wiring was connected to be low potential. This connection realized a beam convergence effect which characterized the present invention.

[0160]

In the above-described arrangement, each element can be selected by using the passive-matrix wiring to be driven independently.

[0161]

An image forming apparatus constructed by using an electron source having such a passive matrix array will be described with reference to Fig. 9. Fig. 9 is a diagram showing the display panel of the image forming apparatus.

[0162]

Referring to Fig. 9, the electron source having the plurality of electron-emitting devices is provided on an electron source substrate 81. The substrate 81 is fixed on a rear plate 91. A face plate 96 has a glass substrate 93, a phosphor film 94 provided as a light emitting member on the internal surface of the glass substrate 93, a metal back 95, etc. The rear plate 91 and the face plate 96 are connected to a supporting frame 92 by using frit glass or the like. An envelope 98 is formed by being seal-bonded by baking in a vacuum at about a temperature of 450°C for 10 minutes. The electron-emitting devices 84 correspond to the electron-emitting regions shown in Fig. 9. X-direction wiring 82 and Y-direction wiring 83 are connected to the pairs of electrodes of the electron-emitting elements in this embodiment.

[0163]

The envelope 97, as described above, is constituted by the face plate 96, the supporting frame 92, and the rear plate 91. A supporting member (not shown) called a spacer is provided between the face plate 96 and the rear plate 91 to enable the envelope 98 to have a sufficiently high strength for resisting atmospheric pressure.

[0164]

After fabrication of the phosphor film, the metal back 95 was made by smoothing the inner surface of the phosphor film (ordinarily called "filming") and by thereafter depositing Al by vacuum evaporation or the like.

[0165]

The face plate 96 further had a transparent electrode (not shown) provided on outer surface of the phosphor film 94 to improve the conductivity of the phosphor film 94.

[0166]

At the time of the performance of the seal-bonding mentioned above, it is necessary for opposing fluorescent materials of each color to the electron-emitting device in case of the color image-forming apparatus, and sufficient alignment is indispensable.

[0167]

In the present example, because the electrons to be emitted from the electron source were emitted to the gate electrode side, the fluorescent materials corresponding to the electron source were arranged to shift to the gate side by 200 μm in the case where the anode voltage was 10 KV and the anode distance was 2 mm.

[0168]

The scanning circuit 102 will be described. The scanning circuit 102 includes M switching devices (schematically shown as S1 to Sm in the figure). Each of the switching devices S1 to Sm selects one of the output voltage from a direct-current voltage source Vx and 0 (V) (ground level). The switching devices S1 to Sm are respectively connected to terminals Dx1 to Dxm of the display panel 101. Each of the switching devices S1 to Sm operates on the basis of a control signal Tscan output from a control circuit 103, and may be a combination of a switching device such as a field-effect transistor (FET) and other components.

[0169]

In this example, the direct-current voltage source Vx is configured to output a constant voltage such that the drive voltage to be applied to a device which is not scanned on the basis of characteristics of the electron-emitting device (electron emitting threshold value voltage), is not higher than the electron-emitting threshold value voltage.

[0170]

The control circuit 103 has the function of matching the operations of the components with each other to suitably perform display on the basis of input signals externally supplied. The control circuit 103

generates control signals Tscan, Tsft, and Tmry to the components on the basis of sync signal Tsync supplied from a sync signal separation circuit 106.

[0171]

The sync signal separation circuit 106 is a circuit for separating sync signal components and luminance signal components from an NTSC television signal externally supplied. This circuit can be formed by using an ordinary frequency separation (filter) circuit, etc. The sync signal separated by the sync signal separation circuit 106 is formed of a vertical sync signal and a horizontal sync signal. However, it is shown as Tsync in the figure for convenience sake. Image luminance signal components separated from the television signal are shown as DATA signal for convenience sake. The DATA signal is input to a shift register 104.

[0172]

The shift register 104 is a device for serial to parallel conversion, with respect to each image line, of the DATA signal which is input in time sequence. The shift register 104 operates on the basis of control signal Tsft supplied from the control circuit 103. (That is, control signal Tsft may be considered to be a shift clock for the shift register.) Data

corresponding to one image line after serial to parallel conversion (corresponding to data for driving N electron-emitting devices) is output as N parallel signals Id1 to Idn from the shift register 104.

[0173]

The line memory 105 is a storage device for storing data corresponding to one image line for a necessary time period. The line memory 105 stores the contents of the signals Id1 to Idn according to control signal Tmry supplied from the control circuit 103. The stored contents are output as I'd1 to I'dn to be input to a modulation signal generator 107.

[0174]

The modulation signal generator 107 is a signal source for suitably modulating signals for driving the electron-emitting devices according to image data items I'd1 to I'dn. Output signals from the modulation signal generator 107 are applied to the electron-emitting devices in the display panel 111 through terminals Doy1 to Doyn.

[0175]

As described above, each electron-emitting device to which the present invention can be applied has basic characteristics described below with respect to emission current Ie. That is, there is a definite

threshold value voltage Vth with respect to emission of electrons. Emission of electrons is caused only when a voltage higher than Vth is applied. When a voltage higher than the electron emission threshold value is applied to the electron-emitting device, the emission current changes according to changes in the applied voltage. Therefore, in a case where a voltage in the form of pulses is applied to the electron-emitting device, electron emission is not caused when the value of the applied voltage is lower than the electron emission threshold value, but an electron beam is output when the value of the applied voltage is equal to or higher than the electron emission threshold value. In this case, the strength of the electron beam can be controlled by changing the pulse crest value Vm. Also, the total amount of charge of the output electron beam can be controlled by changing the pulse width Pw.

[0176]

Therefore, a voltage modulation method, a pulse-width modulation method or the like can be used as a method for modulating the electron-emitting device according to the input signal. If the voltage modulation method is carried out, a voltage modulation type of circuit capable of generating voltage pulses having a constant duration, and modulating the pulse

crest value according to input data may be used as modulation signal generator 107.

[0177]

If the pulse-width modulation method is carried out, a pulse-width modulation type of circuit capable of generating voltage pulses having a constant crest value and modulating the pulse width of the voltage pulses according to input data may be used as modulation signal generator 107.

[0178]

Each of the shift register 104 and the line memory 105 used in this embodiment is of a digital signal type.

[0179]

In this example, a digital to analog converter circuit, for example, is used in the modulation signal generator 107, and an amplifier circuit, etc., are added if necessary. For example, in the case where the pulse-width modulation method is used, a combination of a high-speed oscillator, a counter for counting the number of waves output from the oscillator, and a comparator for comparing the output value of the counter and the output value of the above-described memory is used in the modulation signal generator 107.

[0180]

The configuration of the image forming apparatus described above is an example of the image forming apparatus to which the present invention can be applied. Various modifications and changes can be made therein on the basis of the technical spirit of the present invention. The input signal is not limited to the above-mentioned NTSC signal. Those in accordance with the PAL system and the SECAM system and other TV signals corresponding to a larger number of scanning lines (e.g., those for the MUSE system and other high-definition TV systems) may also be used.

[0181]

[Effects of the Invention]

According to the present invention, as described above, the specific capacitance of an electron-emitting device can be reduced and the drive voltage can also be reduced. An electron source having improved efficiency and a smaller beam size can be realized by using such an electron-emitting device.

[0182]

Moreover, because an image forming apparatus according to the present invention is composed of the electron source, and forms an image on the basis of input signals, an image forming apparatus having higher resolution, e.g., a color flat-screen television, can

be realized.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a diagrams showing an example of a basic electron-emitting device in accordance with the present invention.

[Fig. 2]

Fig. 2 is a diagram showing a second example of the present invention.

[Fig. 3]

Fig. 3 is a diagram showing a third example of the present invention.

[Fig. 4]

Fig. 4 is a diagram showing a fourth example of the present invention.

[Fig. 5]

Fig. 5 is a diagram showing fabrication steps in a first example of the present invention;

[Fig. 6]

Fig. 6 is a diagram showing an example of an arrangement for operating the electron-emitting device of the present invention.

[Fig. 7]

Fig. 7 is a diagram showing an example of an operating characteristic of the basic electron-emitting

device of the present invention.

[Fig. 8]

Fig. 8 is a diagram showing an example of the configuration of a passive matrix circuit using a plurality of electron sources in accordance with the present invention.

[Fig. 9]

Fig. 9 is a diagram showing an example of the construction of an image forming panel using the electron source of the present invention.

[Fig. 10]

Fig. 10 is a diagram showing an example of a circuit for the image forming panel using the electron source of the present invention.

[Fig. 11]

Fig. 11 is a diagram schematically showing the structure of a carbon nanotube.

[Fig. 12]

Fig. 12 is a diagram schematically showing the structure of a graphite nanofiber.

[Fig. 13]

Fig. 13 is a diagram showing a conventional vertical FE structure.

[Fig. 14]

Fig. 14 is a diagram showing an example of a

conventional lateral FE structure.

[Description of Reference Numerals or Symbols]

1 … substrate

2 … gate electrode

3 … electrode

4 … electron-emitting material

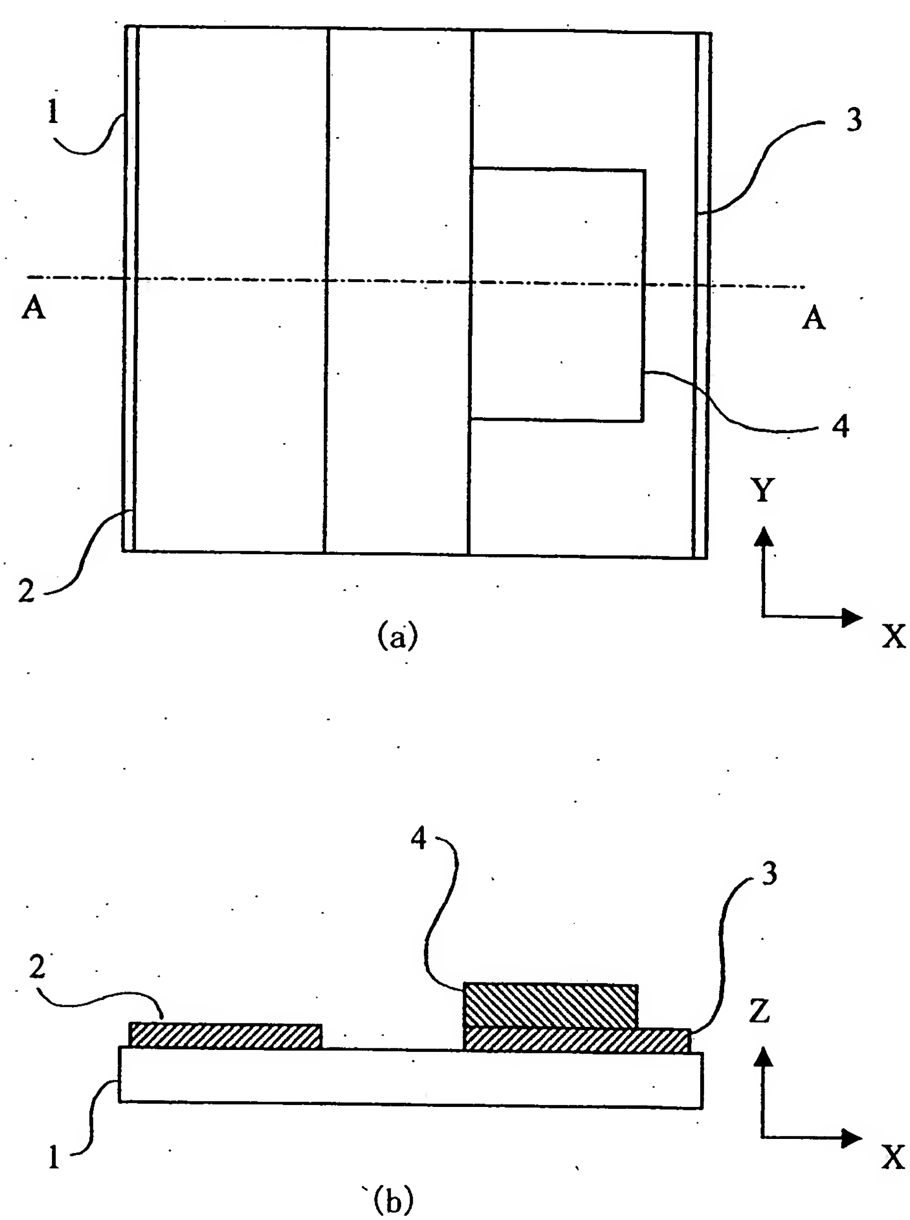
61 … anode

81 … electron source substrate

84 … electron-emitting device

【書類名】　図面

【図１】



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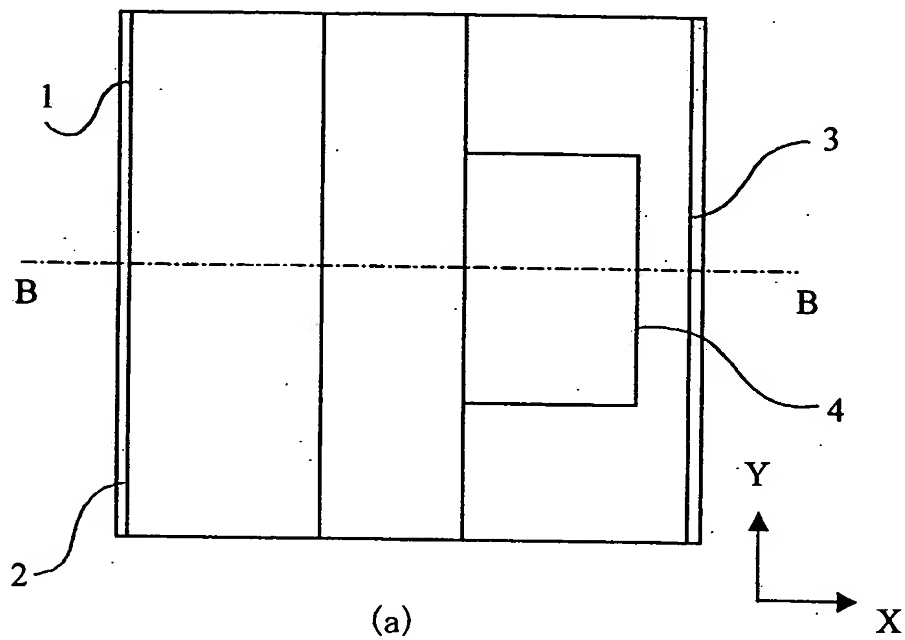

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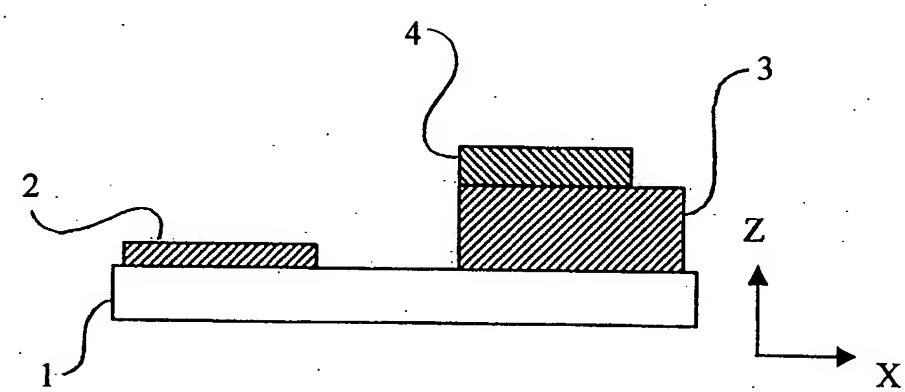

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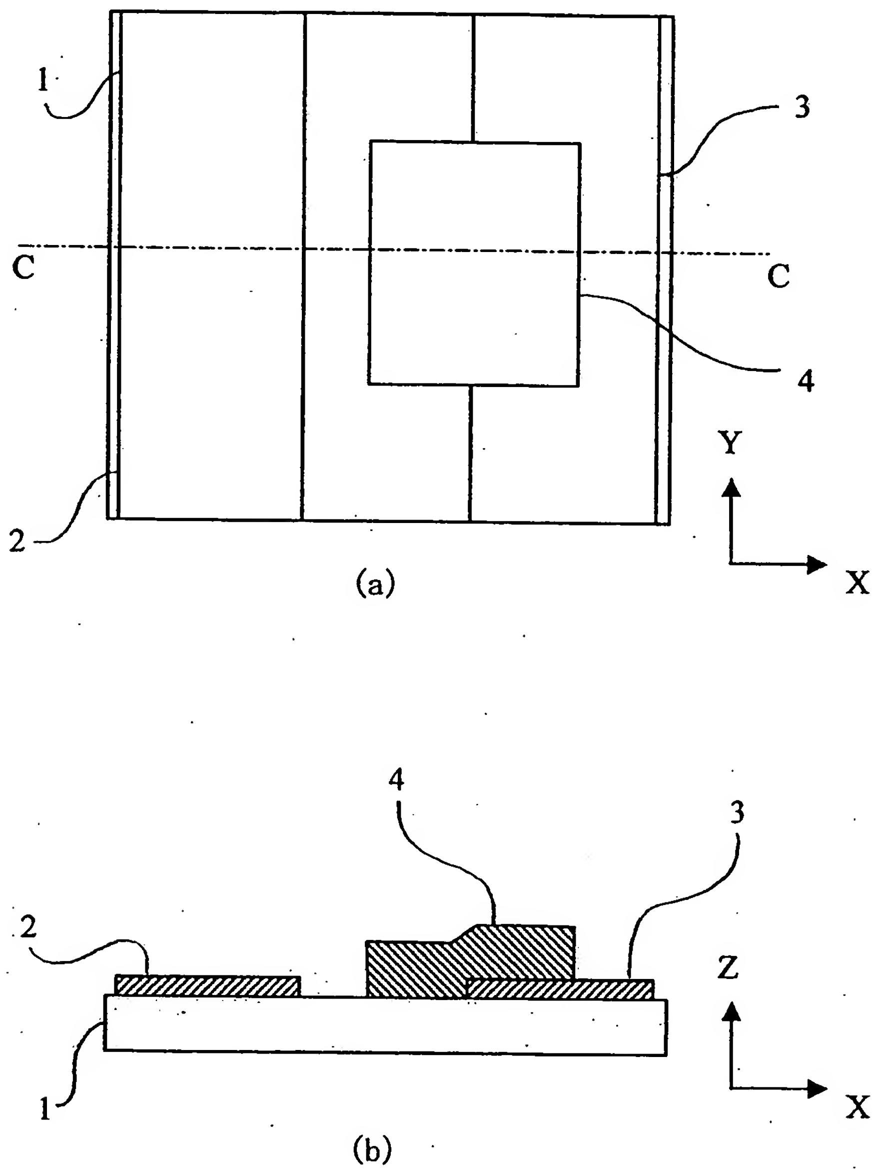

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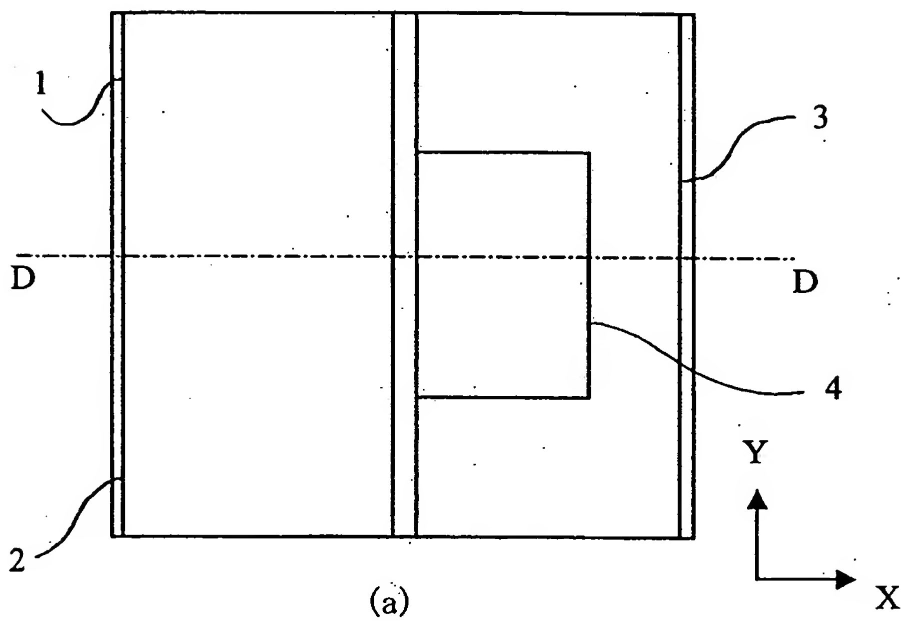

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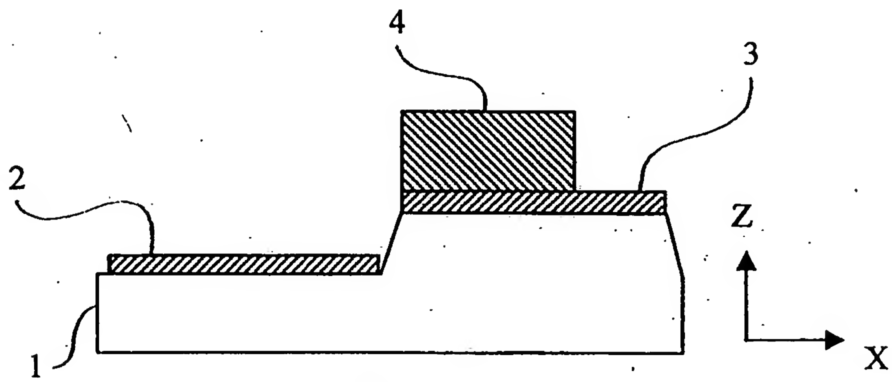

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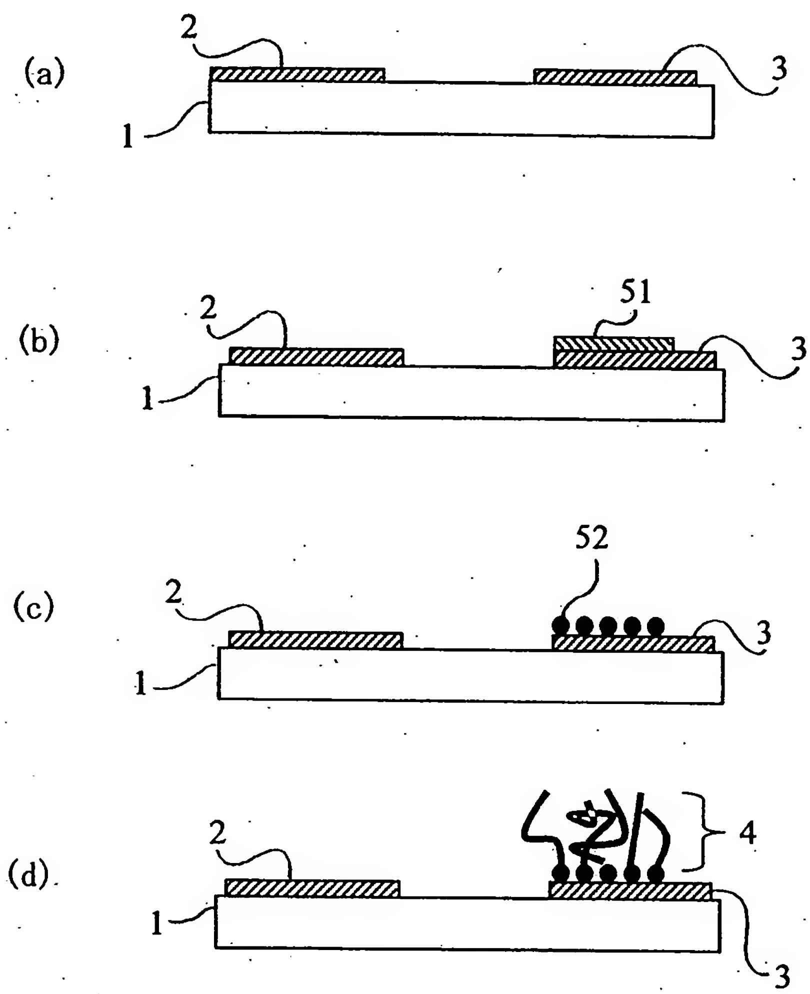

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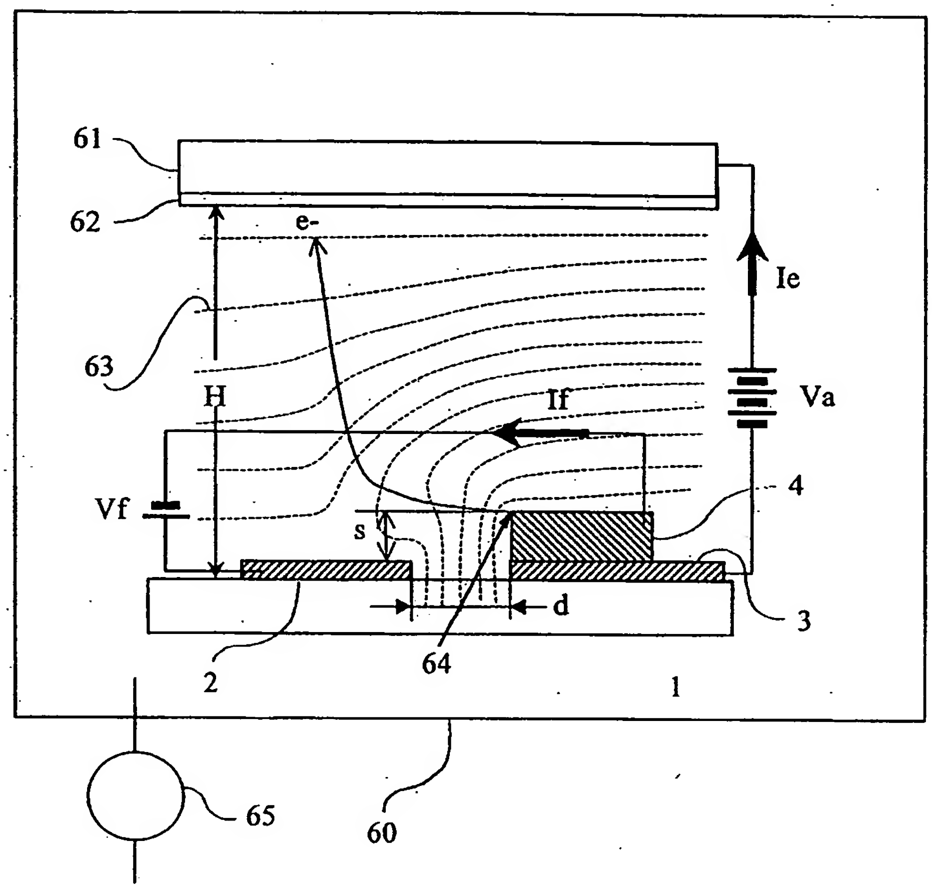

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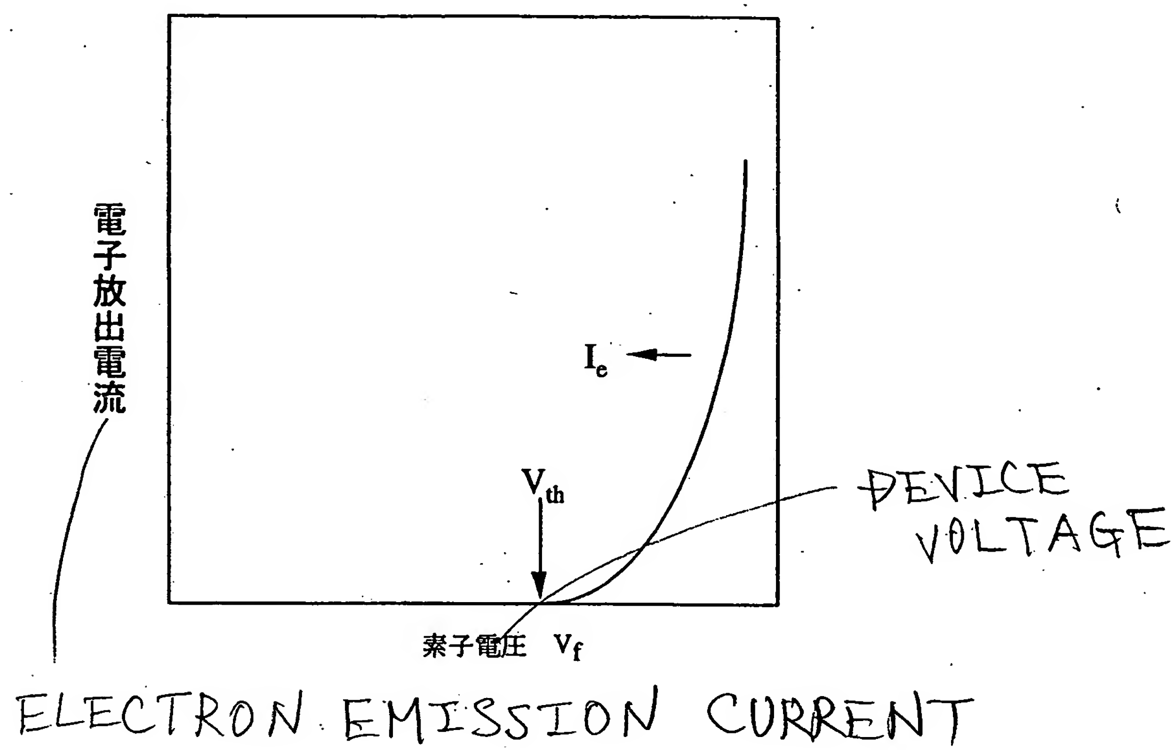
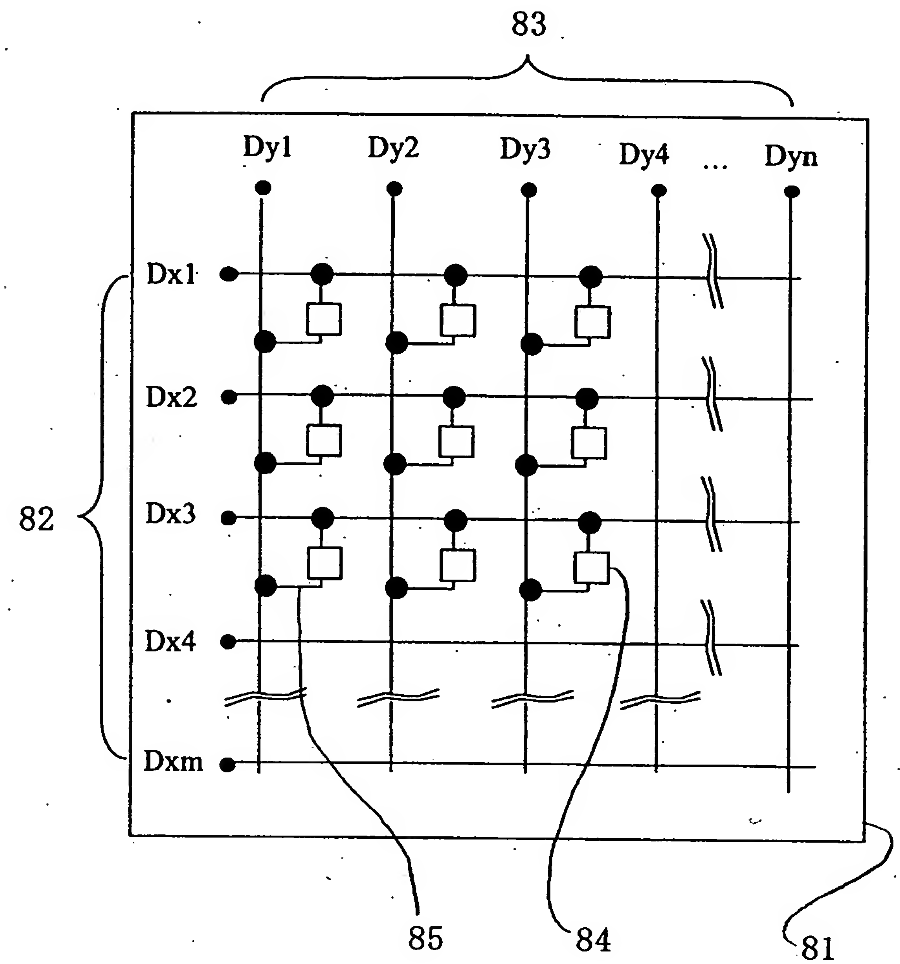

電子放出電流
I_e
V_{th}
素子電圧　V_f
DEVICE VOLTAGE
ELECTRON EMISSION CURRENT

【図８】



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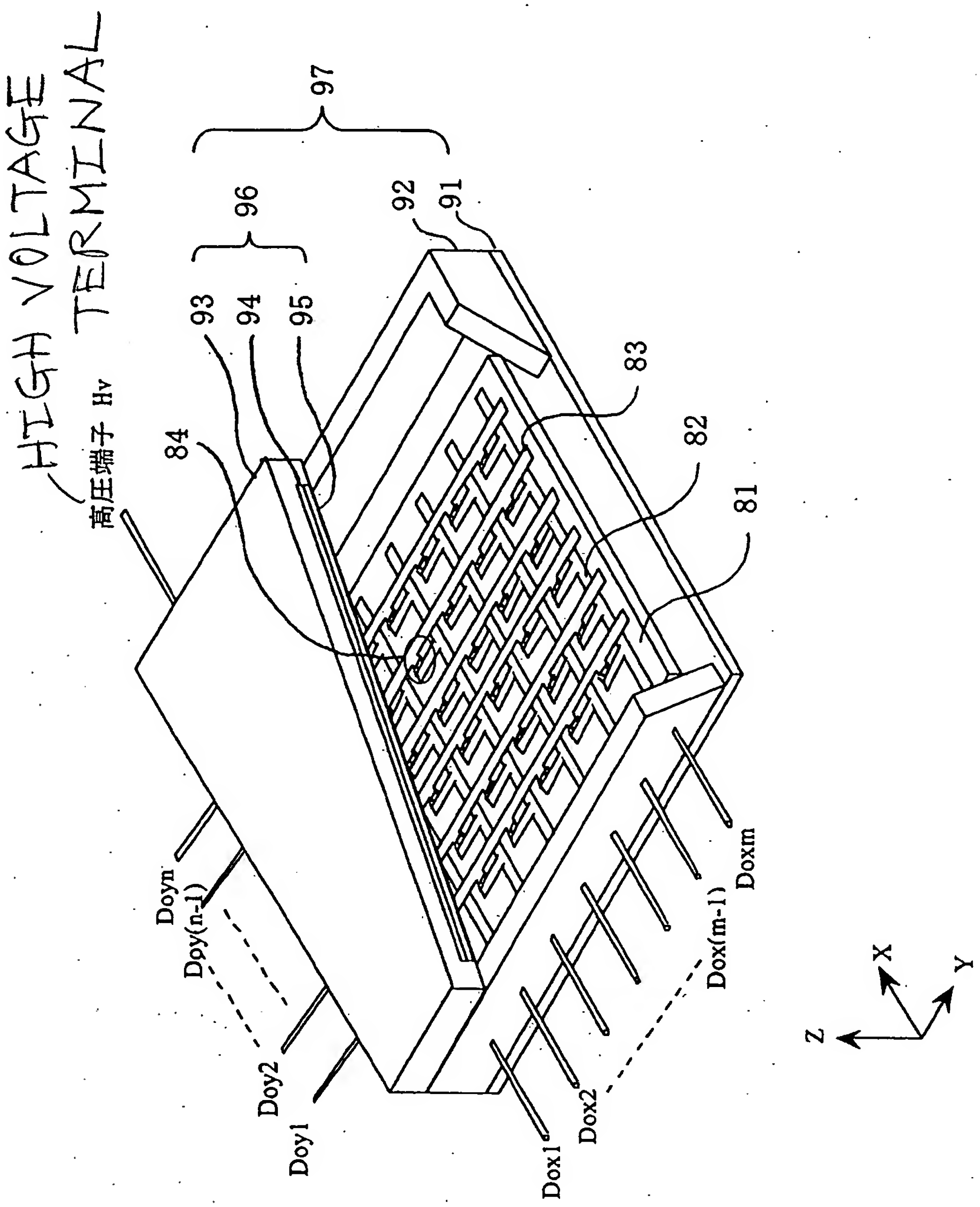
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高圧端子 Hv
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96
93
94
95
92
91
84
83
82
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Doyn
Doy(n-1)
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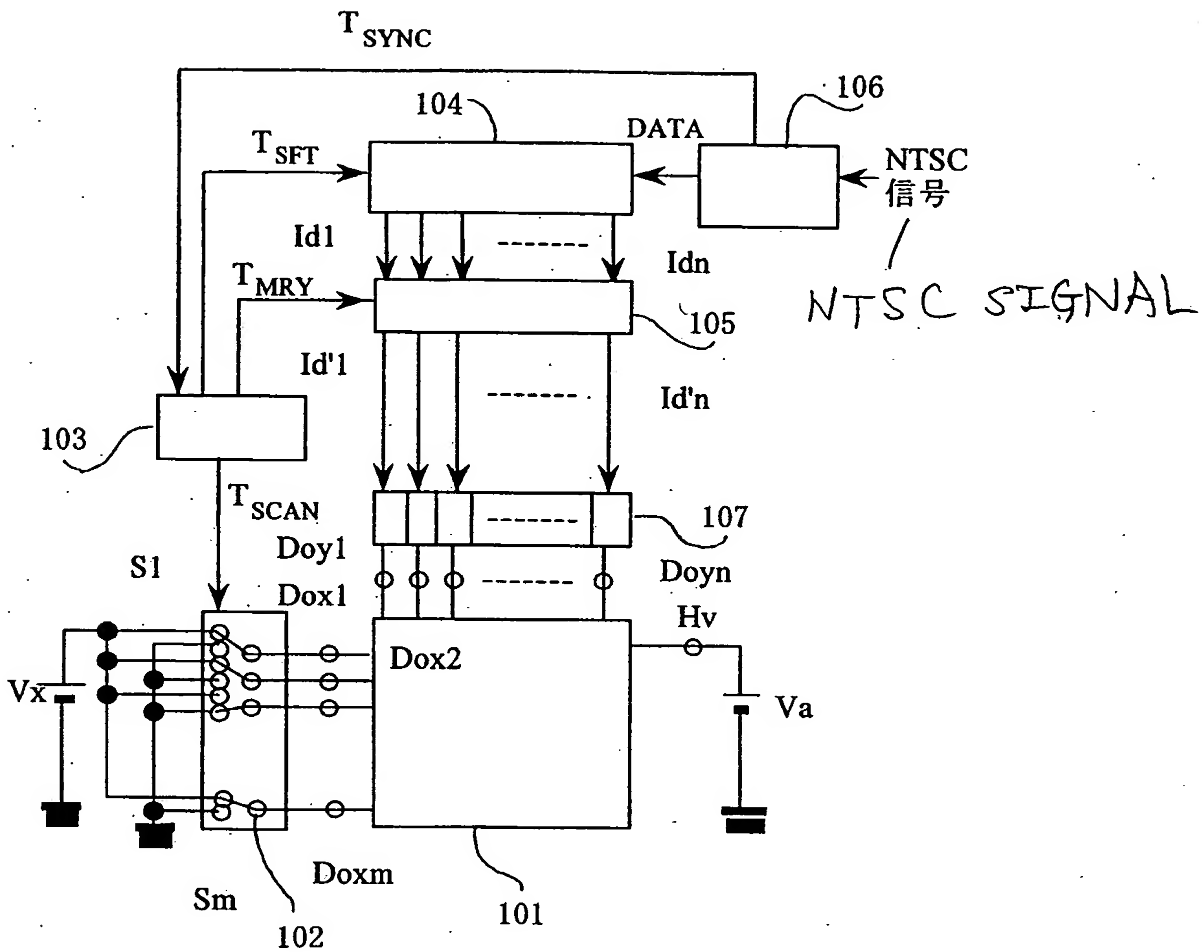
Doy1
Dox1
Dox2
Dox(m-1)
Doxm
X
Y
Z

【図１０】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104
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信号
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101
102

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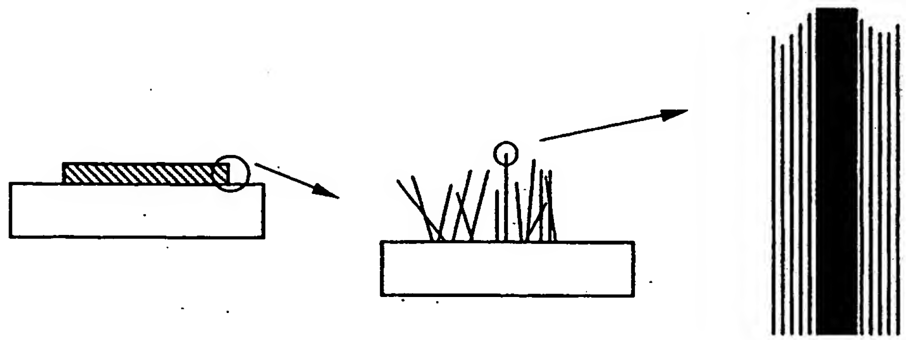

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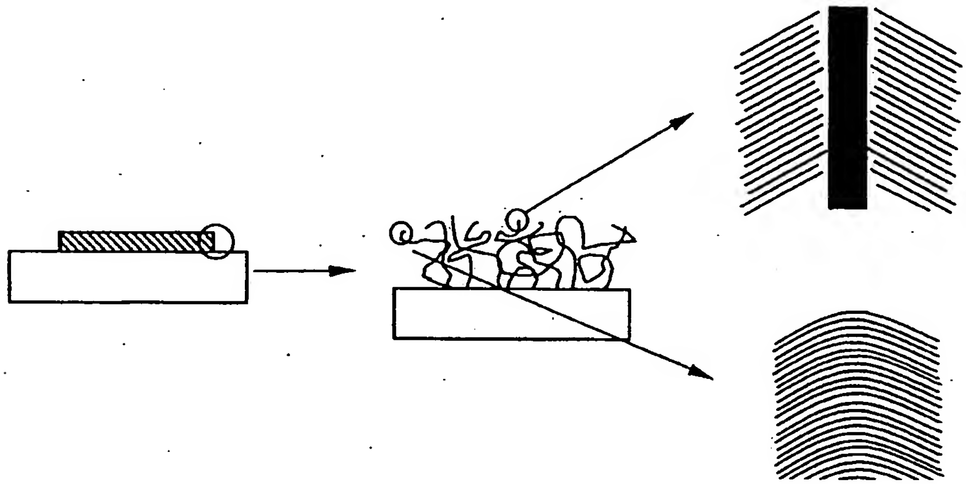

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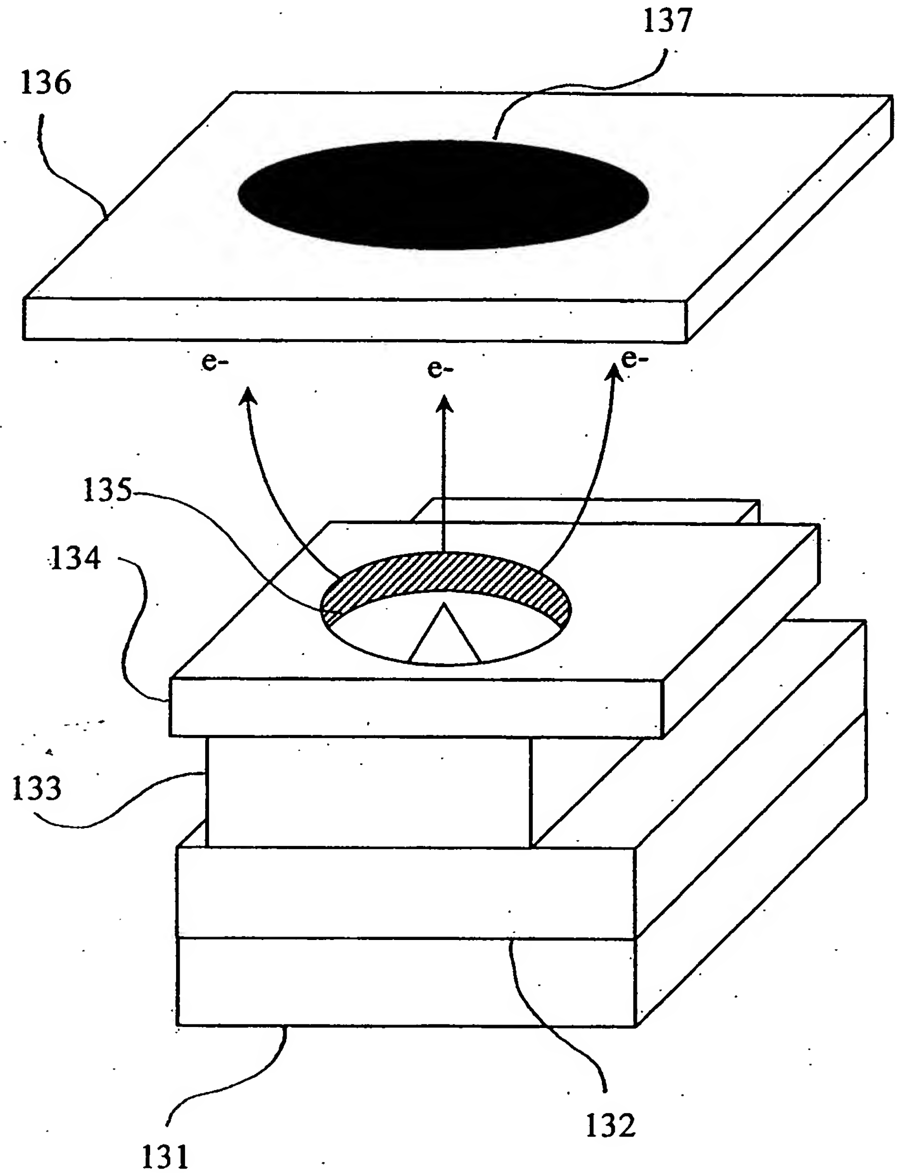

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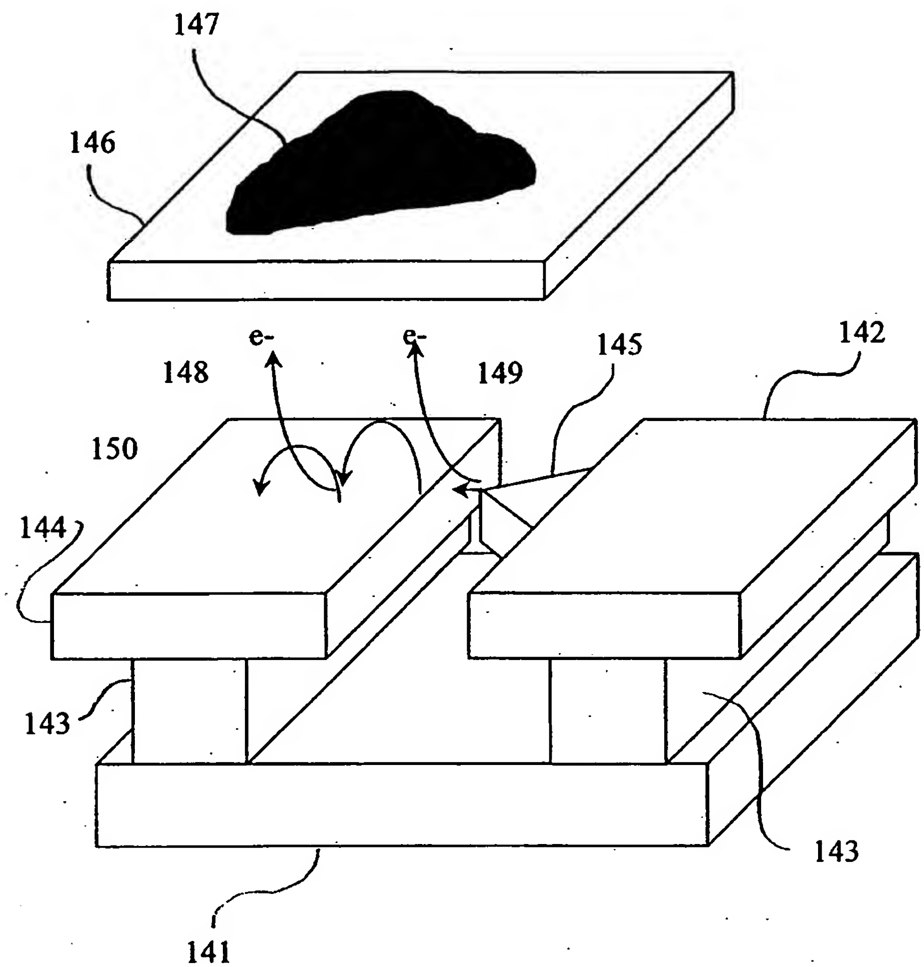

[Name of the Document] Abstract

[Abstract]

[Object]

An electron-emitting device in which the specific capacitance and the drive voltage are reduced, and which is capable of obtaining a finer electron beam by controlling the trajectory of emitted electrons.

[Means for Achieving the Object]

An electron-emitting portion of an electron-emitting member is positioned between the height of a gate and the height of an anode. When the distance between the gate and a cathode is d; the potential difference at driving the device is V1; the distance between the anode and the substrate is H; and the potential difference between the anode and the cathode is V2, then the electric field E1 = V1/d during driving is configured to be within the range from 1 to 50 times E2 = V2/H.

[Selected Drawing]

Fig. 6

2000-265819

Applicant's Information

Identification No. [000001007]

1. Date of Change: August 30, 1990

(Reason for Change) New Registration

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Certificate No. 2001-3083567